EFFECTS OF SUCCESSIVE JUDO MATCHES ON INTERLIMB ASYMMETRY AND BILATERAL DEFICIT

Running title: Interlimb asymmetry after judo matches

Rafael L. Kons[1*]
E-mail address: rafakons0310@gmail.com

Juliano Dal Pupo[1]
E-mail address: dalpupo@gmail.com

Rodrigo G. Gheller[1]
E-mail address: rodrigo.gheller@gmail.com

Filipe E. Costa[1]
E-mail address: lipeestacio@gmail.com

Matheus M. Rodrigues[1]
E-mail address: marinhorodrigues@live.com

Chris Bishop[2]
E-mail address: C.Bishop@mdx.ac.uk

Daniele Detanico[1]
E-mail address: danieledetanico@gmail.com

[1]Biomechanics Laboratory, Center of Sports, Federal University of Santa Catarina, Santa Catarina, Brazil
[2]Faculty of Science and Technology, London Sport Institute, Middlesex University, London, United Kingdom

Corresponding Author:
Rafael Lima Kons
Federal University of Santa Catarina, Center of Sports, Biomechanics Laboratory
ZIP-CODE: 88040-900, Florianópolis, Santa Catarina, Brazil.
Phone: +55 48 3721-8530
E-mail address: rafakons0310@gmail.com

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ABSTRACT

Objective: To verify the effects of successive judo matches on interlimb asymmetry and bilateral deficit in judo athletes.

Design: Repeated measures

Setting: University Judo center

Participants: Fourteen male judo athletes

Outcome measures: Four simulated matches consisting of 4-min. Before the first match and after each match athletes were submitted to single leg tests – Countermovement Jump (SL_{CMJ}) and Standing Long Jump (SL_{SLJ}), and handgrip strength (HGS) in the dominant and non-dominant limbs. Interlimb asymmetry was calculated in both jumps and handgrip strength tests.

Results: Most jump-derived variables did not change the magnitude of asymmetry throughout the matches ($p>0.05$), with the exception of jump height asymmetry in SL_{CMJ}, that increased after the second match ($p=0.001$). The HGS decreased in both hands from the first match ($p<0.001$), without asymmetry. The highest bilateral strength deficit was observed in post-match 1 and post-match 2 (close to 10%).

Conclusion: Four-successive judo matches did not change the magnitude of interlimb asymmetry, with exception of SL_{CMJ} height, which increased after the second match. The handgrip strength decreased throughout the matches, but similarly in both hands. Finally, the direction of asymmetry showed consistency throughout the matches only for SL_{CMJ} height.

Keywords: combat sports, handgrip strength, bilateral deficit, jump.

INTRODUCTION

In official judo competitions, athletes frequently compete over several bouts (typically 4 to 5) that are usually separated by 10-15 minute intervals (Detanico, Dal Pupo, Franchini, & Santos, 2015; Franchini, Takito, Nakamura, Matsushige, & Kiss, 2003; International Judo Federation – IJF, 2020). During the match, judo athletes are engaged in high-intensity actions with sequences of 20-30 seconds of high-intensity efforts, interspersed by 7-10 seconds pauses (Franchini, Artioli, & Brito, 2013). The demand on both upper and lower limbs is extremely high, especially during pulling and pushing movements to maintain the handgrip on the *judogi* (judo-specific jacket) for subsequent attacks (Calmet, Miarka, & Franchini, 2010; Kons, Dal Pupo, Ache-Dias, & Detanico, 2018b). Moreover, there is a high neuromuscular demand to perform the throwing techniques (Detanico et al., 2015), as well as to maintain the body control of the opponent on the groundwork (Nagai, Takito, Calmet, Pierantozzi, & Franchini, 2019).

In this context, the occurrence of progressive fatigue is inevitable during a judo tournament. In general, muscle fatigue causes change in muscle function, which may affect parameters related to neuromuscular performance. A recent systematic review observed that both upper and lower limb performance are affected by repeated matches in grappling combat sports (e.g. judo, Brazilian jiu-jitsu and wrestling) when assessed by handgrip strength and vertical jump tests (Kons, Orssatto, & Detanico, 2020). Specifically, a decrease in jump height performance of 3.6% after the second judo simulated match was verified (Detanico et al., 2015), while handgrip strength decreased by close 15% after the second simulated match (Bonitch-Domínguez, Bonitch-Góngora, Padial, & Feriche, 2010) and 12% after the third official match in dominant hand (Kons et al., 2018b). These findings demonstrated that high muscle fatigue was present in upper and lower limbs after successive competitive bouts in judo athletes.

Recently, more attention has been paid to the effects of fatigue on interlimb asymmetry. Despite the fact that some level of asymmetry is considered acceptable in athletes, values greater than 15% between the limbs may indicate a predisposition to injury incidence (Bishop, Turner, & Read, 2018a; Maloney, 2019) as well as affecting performance (Maloney, 2019; Bishop et al., 208a; Bishop, Read, Stern, & Turner, 2020). However, this relationship between asymmetry and performance is not very clear, when considering the primary characteristics of different sports (e.g., cyclic or acyclic sports) (Bishop et al., 2018a). In judo, a recent study verified an inverse relationship between lower limb asymmetry (unilateral jump height) and judo-specific performance (Special Judo Fitness Test – SJFT) (Kons et al., 2019), demonstrating that interlimb lower limb asymmetry may detrimentally impact on the performance in sport-specific tasks.

It has been suggested that accumulated fatigue in the upper and lower limbs may induce muscle imbalance and has the potential to accentuate asymmetries between the lower limbs (Bishop et al., 2019; Bishop et al., 2020; Bromley et al., 2019; Radzak, Putnam, Tamura, Hetzler, Stickley, 2017). Considering that judo-specific tasks are usually performed unilaterally (e.g., throwing techniques), it is possible that the accumulated fatigue over repeated matches (Bonitch-Góngora et al., 2012; Detanico et al., 2015; Kons et al., 2018b) may occur more prominently on the dominant side; thus, altering the pattern of asymmetry during subsequent testing. However, such a hypothesis still needs to be investigated in combat sports, especially in judo.

Therefore, this study aimed to verify the effects of successive judo matches on unilateral performance, interlimb asymmetry and bilateral deficit in judo athletes. We hypothesized that simulated judo matches will induce an increase of interlimb asymmetry in the upper and lower limbs. Assuming the existing relationship between asymmetry and performance (Kons et al., 2019), this study may help coaches to better understand the consequences of fatigue on performance during a judo competition. In addition, it may also help to prevent the risk of injuries throughout the season based on the assumption that between-limbs asymmetry can increase muscle-related disorders (Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007).

METHODS

Participants

Fourteen male judo athletes participated in the present study, presenting the following characteristics: 23.3 ± 3.0 years, 74.4 ± 22.3 kg, 176.0 ± 5.2 cm, 14.6 ± 5.2% of body fat and time of judo practice of 14.7 ± 3.6 years. All athletes competed at national tournaments and were engaged in regular training (technical−tactical and physical training) 3-4 times a week, at either brown or black belt. The inclusion criterion were: to report no musculoskeletal disorders or injuries at least 1 year before the evaluations or physical restrictions that could influence their maximal performance and to have been training regularly for at least 2 years. Athletes were instructed not to intake alcohol or medication for at least 48-h before and during the evaluations, and to maintain their normal diet. Before the assessments, all participants were informed about the procedures and signed an informed consent form. This study was approved by the Research Ethics Committee of the local University, in accordance with the Declaration of Helsinki.

Study design

We investigated the acute effects of four simulated judo matches on interlimb asymmetries in the single leg jumps and handgrip strength test. The simulated judo contest consisted of four 4-minute judo matches (actual combat time) separated by 15 minutes of passive rest. Athletes performed single leg jump assessments (vertical and horizontal) and maximal isometric handgrip strength test in randomized order before the first match (baseline) and immediately after each match (i.e., in each post-match assessments the tests were randomized). All athletes attended a familiarization session one week before the experimental protocol.

<u>Simulated Judo Matches</u>

Before initiation of the simulated matches, athletes performed a judo-specific warm-up consisting of dynamic stretching of upper and lower limbs, judo-specific falls and throwing techniques application (e.g., *o-soto-gari, seoi-nage,* etc.) lasting approximately 15 minutes. Afterward, athletes performed 4 x 4-minute simulated judo matches separated by 15 minutes interval. The athletes were informed that they must complete all four matches. In the event of *ippon* (score that determines the end of the match), the match was restarted to guarantee that all athletes competed for the same combat duration in all four matches. The participants were divided into pairs with a difference of body mass no more than 10% between them. This protocol reproduced the real judo combat activity (temporal structure) as described in the correlating literature (Bonitch-Góngora et al., 2012; Detanico et al., 2015). The interval between the end of each match and post-match assessments was from 6 to 8 min (i.e. considering total of 15 minutes interval, the athletes had 7-9 minutes of passive rest). This interval was determined in a pilot study and according to a previous study (Detanico et al., 2015), as it was a minimum time to allow the displacement of the athletes from the dojo (where matches were simulated) to Biomechanics Laboratory. During the assessments, the temperature was 24°C in the laboratory and 24°C in the *dojo* (judo training hall).

Single Leg Tests – Countermovement Jump (SL_{CMJ}) and Standing Long Jump (SL_{SLJ})

Before testing, athletes performed a warm-up consisting of two sets of ten hops on the ground, 3-5 submaximal countermovement jumps, 4 single leg countermovement jumps (SL_{CMJ}) and 4 submaximal single leg standing long jumps (SL_{SLJ}) for each limb: dominant and non-dominant as reported by athletes. After three-minutes of rest, subjects were assessed in the SL_{CMJ} or SL_{SLJ} in randomized order. The mean of the four jumps (SL_{CMJ} and SL_{SLJ}) was used to determine each variable.

Athletes were asked to stand in the center of a piezoelectric force platform (Model 9290AD, Quattro Jump, Winterthur, Switzerland) with hands on their hips (for controlling arm contribution). To begin the test, one leg was lifted off the floor, and then the subjects performed a countermovement, followed by a rapid extension of the lower limb joints, with the intention of jumping as high as possible. The participants were instructed to jump using a preferred squat depth; then, they were familiarized to maintain their jumps consistent (i.e. similar technique and knee flexion angle in all attempts). Each subject performed three maximal SL_{CMJ} on both limbs at baseline and immediately after each match. The ground reaction force (GRF) data registered were filtered by a fourth-order low-pass Butterworth filter at 20 Hz, determined from power spectral analysis. The variables obtained from the force-time curve were: a) jump height (JH) – obtained by double integration of the GRF; b) peak (PPO) and mean power output (MPO) – calculated by multiplying the GRF by velocity in concentric phase of the jump; c) peak force (PF) – highest value obtained in the concentric phase of the jump, expressed in absolute terms (N); d) peak velocity (PV) – highest value obtained in curve of velocity, observed immediately before the loss of foot contact with the ground (take-off); e) vertical impulse (VI) – determined during the concentric phase of the jump.

For the SL_{SLJ}, the athletes were positioned with their toes behind the starting line corresponding to the zero point of the measuring tape (Lufkin, L716 MAGCME; Apex Group, Sparks, Maryland) fixed to the floor. From this position, they initiated the countermovement of the lower limb and arm swing to aid in obtaining the maximum possible distance. The distance from the starting line to the nearest point of landing contact (i.e., back of the heel) was measured. The participants performed three maximal SL_{SLJ} on both limbs at baseline and immediately after each match.

Maximal Handgrip Strength Test

The maximal isometric handgrip strength was measured using an analogic dynamometer (Carci®, HS5001 model, São Paulo, Brazil). Before the test, athletes performed a warm-up consisting of two sets of five submaximal handgrip strength. The assessments were performed before the first match (baseline) and immediately after each match in the dominant and non-dominant hand, and in both hands at the same time. The individuals were instructed to perform the test with maximal effort during 5 seconds, in a standing position, shoulder at 90º of flexion and elbow completely extended, following similar protocols (Bonitch-Góngora et al., 2012; Kons et al., 2018b). The same instructions, positions and shoulder flexion angle were performed during all evaluations (pre- and post-tests) as recommended by Wilson and Murphy (1996) for isometric tests. The time between attempts was approximately 30-60 seconds. The mean of three handgrip strength attempts was used for further analysis.

Interlimb Asymmetry and Bilateral Deficit Index

Interlimb asymmetry (magnitude) was quantified as the percentage of difference between the stronger and weaker limb using the equation 1 proposed by Impellizzeri et al. (2007) and Bishop, Read, Lake, Chavda and Turner (2018b) and recently used in a similar study design (Bishop et al., 2020). We calculated the asymmetry index from the stronger and weaker limb for handgrip strength (peak force), SL_{SLJ} (distance) and for each SL_{CMJ} performance variable (jump height, force, impulse, power and velocity).

$$\text{Interlimb asymmetry} = \frac{\text{(Stronger limb - Weaker limb)}}{\text{Stronger limb}} * 100 \qquad \textbf{Equation 1}$$

For individual analysis of the direction of asymmetry, a negative sign (−) was arbitrarily assigned when the left lower limb was the stronger one, and a positive sign (+) when the right lower limb was the stronger one.

The bilateral index (BI), which is the ratio between bilateral and unilateral values of handgrip strength, was calculated from the left unilateral, right unilateral and bilateral values of the handgrip strength tests, as can be seen in Equation 2 (Howard & Enoka, 1991).

$$\text{BI (\%)} = \left[100 * \left(\frac{\text{bilateral}}{\text{left unilateral + right unilateral}}\right)\right] \text{-100} \qquad \textbf{Equation 2}$$

A bilateral facilitation was indicated if the BI was significantly greater than 0, and a bilateral deficit was indicated if the BI was significantly less than 0. The presence of a bilateral deficit was considered a significant difference of bilateral tasks in comparison to the sum of the unilateral tasks. This analysis was recently used with judo athletes (Turnes, Silva, Kons & Detanico, 2019).

Statistical Analysis

The Intraclass Correlation Coefficient ($ICC_{3:1}$ – consistency) and Typical Error (TE) were used as relative and absolute reliability indicators, respectively, for handgrip strength test and single leg jumping tests. ICC and TE were calculated from the three trials before testing. TE was calculated by dividing the standard deviation (SD) of the difference between three trials (pre-condition) by $\sqrt{2}$ with a 95% confidence interval (CI) (Hopkins, 2000) and expressed as a coefficient of variation (CV). We used the interpretation of ICC values as follow: > 0.9 = excellent, 0.75-0.9 = good, 0.5-0.75 = moderate, and < 0.5 = poor (Koo & Li, 2016). Data normality was tested using Shapiro-Wilk and the equality of variances assumption using Levene's test. If the Levene's test identified that variances were not equal ($p<0.05$), the Kruskal-Wallis non-parametric test was adopted. A t-test for independent sample (normal data) was used to compare the variables in the pre-condition (baseline) between the dominant and non-dominant limbs.

The analysis of variance (ANOVA) two-way repeated measures (time *vs.* limb) was used to analyze the interaction and time-effect of the dependent variables. The effect size (ES) was calculated through the partial eta squared (η_p^2) from ANOVA. The criterion classification of the ES was < 0.01 small, 0.06 medium and > 0.14 large effect (Cohen, 1998). The interlimb asymmetry data for a single leg jump and handgrip strength tests did not present a normal distribution ($p<0.05$); thus, the analyses was performed by the Friedman test with Conover's post hoc. An alpha level of 0.05 was used in all statistical analyses. For non-parametric analyses, the ES was derived from Friedman Chi Square (X^2) and calculated from the omega squared (ω^2) with the criterion classification: < 0.01 very small, 0.06 small, 0.14 moderate and > 0.14 large. Finally, Kappa coefficients were calculated to determine the levels of agreement for how consistently asymmetry favored the same side (between pre and post-matches) when comparing the different time points measured. The Kappa coefficient was interpreted in line with suggestions from Viera and Garrett (2005), where: < 0 poor, 0.01–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–0.99 almost perfect. All statistical analyses were conducted with JASP software (version 0.11.1, JASP team, University of Amsterdam, Netherlands).

RESULTS

Table 1 shows the comparison between the dominant and non-dominant limbs before the testing (three trials) for SL_{CMJ}, SL_{SLJ} and handgrip strength in order to verify the pre-condition of the athletes. In addition, the ICC and TE were presented to show the reliability of the values. A significant difference was found only for distance in SL_{SLJ}, with the dominant limb outperforming the non-dominant limb. Excellent relative reliability (ICC) was observed for all variables in both limbs (ICC > 0.85). The absolute reliability (TE) was slightly higher in the non-dominant limb compared to the dominant in most neuromuscular performance parameters.

****Insert Table 1 here****

Table 2 shows the comparison of SL_{CMJ} parameters, SL_{SLJ} performance and handgrip strength performance throughout judo matches for the non-dominant and dominant limbs. ANOVA showed no significant interaction between time and limb for handgrip strength ($F_{(4,104)}$=0.957, p=0.40, η_p^2=0.04 [small effect], but effect of time ($F_{(4,104)}$=40.42, p<0.001, η_p^2=0.61 [large effect]). Post-hoc analysis showed reduction in handgrip strength performance in both dominant and non-dominant hands throughout successive matches. The SL_{SLJ} showed interaction between time and limb ($F_{(4,104)}$=2.761, p=0.03, η_p^2=0.10 [medium effect]), but the post-hoc analysis did not show significant differences. When analyzed SL_{CMJ} variables, there was no interaction between time and limb, and nor effect of time, respectively, for: jump height ($F_{(4,104)}$=0.889, p=0.45, η_p^2=0.03 [small effect]; $F_{(4,104)}$=1.04, p=0.37, η_p^2=0.04 [small effect]), mean power output ($F_{(4,104)}$=0.821, p=0.49, η_p^2=0.03 [small effect]; ($F_{(4,104)}$=2.51, p=0.06, η_p^2=0.08 [medium effect]); peak power output ($F_{(4,104)}$=0.961, p=0.38, η_p^2=0.04 [small effect]; ($F_{(4,104)}$=0.433, p=0.63, η_p^2=0.02 [small effect]); peak force ($F_{(4,104)}$=0.627, p=0.56, η_p^2=0.02 [small effect]; ($F_{(4,104)}$=0.108, p=0.92, η_p^2=0.01 [medium effect]); peak velocity ($F_{(4,104)}$=1.474, p=0.24, η_p^2=0.05 [small effect]; ($F_{(4,104)}$=1.079, p=0.33, η_p^2=0.04 [small effect]); and impulse ($F_{(4,104)}$=1.215, p=0.31, η_p^2=0.05 [small effect]; ($F_{(4,104)}$=2.211, p=0.09, η_p^2=0.08 [medium effect]).

****Insert Table 2 here****

Figure 1 shows the asymmetry indexes for all parameters of $SL_{CMJ,}$ SL_{SLJ} and handgrip strength at pre-match, post-match 1, post-match 2, post-match 3 and post-match

4. A significant effect of judo matches was found only in the jump height asymmetry ($X^2_{(4,52)}$=11.54, p=0.001, η_p^2=0.88 [large effect]), with higher values at post-match 2 compared to pre (p=0.003), post-match 1 (p=0.012), post-match 3 (p=0.022) and post-match 4 (p=0.050). Considering the magnitude of asymmetry in the SL_{CMJ} (other metrics), SL_{SJL} and handgrip strength test over the matches, no significant differences were found over the simulated judo matches (p>0.05).

****Insert Figure 1 here****

With the intention of showing the individual direction of asymmetry using the most useful variables (for coaches and athletes) in upper and lower limbs, we chose the jump height in SL_{CMJ} and HGS, which were the variables that best represented the performance in each test (Figure 2). We considered right (+) and left (-) limbs in all conditions (pre and after each match) for handgrip strength and jump height in the SL_{CMJ} and maximal handgrip strength, respectively. The Kappa coefficients were calculated to determine the levels of agreement between pre-match values and post-match 1, 2, 3 and 4. In the jump height, we observed a significant and moderate agreement between pre-match and post-match 1, post-match 2 (Kappa=0.57, p=0.03) and post-match 3 (Kappa=0.43, p=0.05). No significant (but moderate) agreement was observed between pre-match and post-match 4 (Kappa=0.42, p=0.09). For handgrip strength values, there were no significant and fair agreement between pre-match and post-match 1, post-match 2, post-match 3 (Kappa=0.28, p=0.29), and no significant (but moderate) agreement between pre-match and post-match 4 (Kappa=0.43, p=0.10).

****Insert Figure 2 here****

The measures of bilateral index (obtained by maximal handgrip strength) in the pre and after each match is presented in Figure 3. A significant difference was observed throughout the matches ($F_{(4,52)}$=2.86, p=0.03, η_p^2=0.55 [large effect]). Post-hoc values showed significant differences only between post-match 3 (-0.6 ± 7.0%) and post-match 4 (-7.5 ± 13%) (*p*=0.03). However, any significant difference was obtained compared to the pre-values. The highest negative values were observed in post-match 1 (-9.2 ± 8.2%) and post-match 2 (-10.4 ± 7.7%).

****Insert Figure 3 here****

DISCUSSION

This study proposed to verify the effects of successive judo matches on interlimb asymmetry (magnitude and direction) of handgrip strength and jump performance in judo athletes. In general, the asymmetry of most jump variables and handgrip strength did not change throughout the matches, with exception of increase in the asymmetry of the SL_{CMJ} height after the second match (Figure 1). The handgrip strength decreased throughout the matches similarly in both hands (Table 2). Finally, the direction of asymmetry showed consistency for jump height throughout the matches.

Initially, good reliability of neuromuscular parameters were found for both limbs (Table 1), showing that the athletes were very familiar with the neuromuscular tests. In general, the non-dominant limb showed higher variability for most neuromuscular metrics, similar to that found by Madruga-Parera et al. (2019), especially for jump height.

In addition, a significant asymmetry was identified for SL_{SLJ} at baseline in favor of the dominant limb. We can speculate that the non-dominant limb is likely to demonstrate reduced motor control, compared to the dominant limb during the single-leg jump tests, producing higher instability mainly during the take-off, which is supported by the reduced jump distance compared to the dominant limb (Kons et al., 2020b).

Our findings showed that four-successive judo matches did not result in a reduction in all unilateral lower limb parameters in the SL_{CMJ} and SL_{SLJ} (Table 2). A previous study with a similar design but using a bilateral CMJ showed that three-successive judo matches induced a decrease in the jump height after second (3.6%) and third match (3.2%) compared to baseline (Detanico et al., 2015), without any changes in power output. In contrast, Bonitch-Domínguez et al. (2012) found no significant differences in the peak power, force and velocity in a bilateral squat test throughout the four judo matches. The absence of changes in unilateral measures verified in our study may suggest that in the unilateral jump testing, some neural mechanism occurs to maintain the force output while protecting the limbs from a possible injury caused by the load imposed by the effort (Gibson, Lambert, & Noakes, 2001) and also associated with the sensitivity of the measurement. However, further investigations need to be undertaken to understand interlimb fatigue throughout the judo matches.

We verified that the parameters of asymmetry from SL_{CMJ} (power output, force, velocity and impulse) and SL_{SLJ} (distance) did not change throughout the matches (Figure 1). We hypothesized that the demand of simulated judo matches could increase asymmetry considering the negative relationship between asymmetry and performance. Our results are similar to those of Bishop et al. (2020) who found no increase in asymmetry after repeated soccer match-play, possibly due to the different intensities and individual strategies adopted by each athlete during matches. Two aspects may explain these results. First, the asymmetry may not be identified because an effect of accumulated fatigue had not been reported (Table 2), or second, these jump mechanical parameters may not be sensitive enough to identify the between-limb asymmetry over successive judo matches. According to Bishop et al. (2020), although the majority of unilateral jump metrics commonly measured during the SL_{CMJ} are sensitive to change after repeated soccer matches, interlimb asymmetry seems to show little consistency with highly variable changes between the assessments. Perhaps, more controlled tasks than simulated matches may be more sensitive to detect changes in the asymmetry. For example, Kons et al. (2019) found a negative correlation between interlimb CMJ height asymmetry and performance in a judo-specific test (Special Judo Fitness Test).

Contrary to single-leg jump performance, the maximal isometric handgrip strength progressively decreased from the first match in both hands (Table 2), showing accumulated fatigue in the forearm muscles throughout the matches. The bilateral index in the handgrip strength was close to 10% after the first and second matches, but without significant difference from pre-test (Figure 3). The bilateral index describes the difference in force generating capacity of muscles when they are contracted alone or together with the contralateral muscle group, i.e. the bilateral deficit (Kuruganti, Murphy, & Pardy, 2011), and represents a control limitation of the neuromuscular system (Jakobi, & Chilibeck, 2001). It is not clear if and how fatigue affects the bilateral deficit, but it is possible to suggest that in a non-fatigued state, the common drive views right and left limb as one unit and controls them in a similar fashion (De Luca, Sabbahi & Roy, 1986).

The reduction in muscle activation associated with the decline in force production has been appointed as a probable cause of bilateral deficit (Howard, & Enoka, 1991).

Vandervoort, Sale and Moroz (1984) suggest that the bilateral deficit results from the inhibition of high threshold fibers, which are recruited when the force must be produced quickly. These fibers are more susceptible to fatigue (Schiaffino & Reggiani, 2011), thus, successive judo matches can alter the fatigue state of this type of muscle fiber and, consequently, the bilateral deficit. From this perspective, an increase in the bilateral deficit may affect the maintenance of grip during the matches and impair performance, since the handgrip strength is considered a determinant aspect for subsequent performance of judo throwing techniques (Calmet et al., 2010; Kons et al., 2018a). However, this assumption needs further investigation.

We hypothesized that successive matches would induce asymmetry considering the high-intensity effort and judo unilateral characteristics, but we found that the asymmetry of handgrip strength did not change throughout the matches (Figure 1). Despite that fatigue was registered unilaterally over the matches, it is possible that the athletes have regulated the intensity of their grips in search for an advantage considering both hands. It is known that in judo combat, the athletes' first action consists of a dispute for gripping (Calmet et al., 2010; Piras, Pierantozzi, & Squarito, 2014), aiming for a possible advantage to perform thereafter judo throwing techniques (Kons et al., 2018a). These actions are performed at high intensity and most likely lead to high levels of fatigue. Several studies have observed a decrease in handgrip strength in both hands after judo combats (8-15% from the third match) (Bonitch-Góngora et al., 2012, Kons et al., 2018b), as previously verified in our study 15% considering the first match, but the fatigue was reported in both hands.

When considering the direction of asymmetry between pre and post-match measurements, our results showed consistency only for SL_{CMJ} height (Figure 2 and Kappa coefficients). It means that regardless of the magnitude of asymmetry, the same limb was consistently outperforming the other for this particular metric. No mechanistic investigation was undertaken, so fully explaining this finding is somewhat challenging. This may be a speculation, that non-dominant limb has lesser resistance to fatigue than the dominant limb; thus, increasing the asymmetry in favor of the same side (De Luca et al., 1986; Zijdewind, Bosch, Goessens, Kandou, & Kernell, 1990). In our study, the limb dominance remained consistent, considering the direction (side) and the magnitude of jump height asymmetry (Δ=0.9% for dominant and 0.5% for non-dominant limb between pre and post-match 4). Thus, it seems that both lower limbs were similarly requested when submitted to the match effort (excluding the measure pre and post-match 2). On the other hand, handgrip strength asymmetry did not show consistency in dominance (direction of asymmetry) when measured after the matches. In addition to the athletes having performed similar effort in both hands during the matches, it is possible that the dominance has a less important role during the matches, but this aspect must be further investigated. Another point may be related to the natural fluctuations in the variability of this variable, since the Kappa coefficients were low.

Finally, a limitation that could be pointed out in our study is that we analyzed simulated judo matches due to the difficulty to evaluate athletes during competition. However, we tried to reproduce the matches as real as possible, respecting, for example, the official time, interval between matches and weight categories. For future studies we recommend using more controlled tasks than simulated matches, in order to increase the sensitivity to detect possible changes in asymmetry. Moreover, a complementary analysis of kinematic parameters such as joint angles (knee and hip) and squat depth could provide more accurate information on motor control in fatigued conditions.

In the practical perspective, interlimb asymmetry has been associated with performance impairment (Kons et al., 2019) and as a possible factor risk of injuries (Impellizzeri et al., 2007). Our findings showed that the magnitude of asymmetry of single leg jump and handgrip strength metrics did not change throughout the judo matches; thus, it does not seem to be an important concern for coaches to monitor asymmetry responses in upper and lower limbs during a judo competition. Caution should be taken about the use of interlimb asymmetry to inform decision-making during the recovery period between judo matches.

CONCLUSION

We concluded that that four-successive judo matches did not change the magnitude of interlimb asymmetry in upper and lower limbs, when assessed by handgrip strength and single leg jump tests. Only the asymmetry of SL_{CMJ} height increased after the second match. The handgrip strength decreased throughout the matches, but similarly in both hands. Finally, the direction of asymmetry showed consistency throughout the matches only for SL_{CMJ} height.

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TABLES

Table 1. Descriptive (Mean ± SD) and reliability values (ICC and TE with 95% confidence intervals) of neuromuscular test performance in the dominant and non-dominant limbs before testing.

SL_{CMJ}	**Mean ± SD**	**p**	**$ICC_{3,1}$ (95% CI)**	**TE (95% CI)**
JH_D (cm)	28.0 ± 3.6	0.41	0.94 (0.86 – 0.98)	5.8 (4.60 – 8.91)
JH_{ND} (cm)	26.7 ± 3.9		0.93 (0.83 – 0.98)	9.4 (7.41 – 14.5)
MPO_D (W)	1162.2 ± 163.6	0.13	0.95 (0.87 – 0.98)	4.66 (3.67 – 7.08)
MPO_{ND} (W)	1303.7 ± 287.0		0.96 (0.92 – 0.99)	8.80 (6.90 – 13.5)
PPO_D (W)	2209.9 ± 316.0	0.12	0.95 (0.89 – 0.98)	4.89 (3.85 – 7.43)
PPO_{ND} (W)	2487.5 ± 550.6		0.96 (0.90 – 0.99)	9.29 (7.27 – 14.2)
PF_D (N)	1472.1 ± 227.4	0.47	0.98 (0.95 – 0.99)	3.32 (2.61 – 5.02)
PF_{ND} (N)	1541.2 ± 251.7		0.97 (0.93 – 0.99)	4.19 (3.30 – 6.35)
PV_D ($m·s^{-1}$)	1.83 ± 0.18	0.22	0.97 (0.94 – 0.99)	2.61 (2.06 – 3.95)
PV_{ND} ($m·s^{-1}$)	1.97 ± 0.35		0.97 (0.94 – 0.99)	6.26 (4.91 – 9.54)
VI_D (N·s)	182.5 ± 25.5	0.26	0.93 (0.83 – 0.97)	8.45 (6.62 – 12.9)
VI_{ND} (N·s)	197.3 ± 38.3		0.89 (0.72 – 0.96)	8.18 (6.42 – 12.5)
SL_{SLJ}				
D (cm)	188.9 ± 23.6*	0.031	0.85 (0.74 – 0.95)	7.43 (5.50 – 11.7
ND (cm)	168.6 ± 23.4		0.95 (0.84 – 0.98)	4.18 (3.11 – 6.55)
HGS				
D (kgf)	58.4 ± 11.6	0.58	0.97 (0.93 – 0.99)	5.96 (4.67 – 8.65)
ND (kgf)	56.3 ± 7.7		0.96 (0.90 – 0.98)	4.62 (3.63 – 6.69)

JH: jump height, MPO: mean power output, PPO: peak power output, PF: peak force, PV: peak velocity, VI: vertical impulse; HGS: handgrip strength, D: dominant, ND: non-dominant, SL_{CMJ}: single leg countermovement jump, SL_{SLJ}: single leg standing long jump. *Difference from non-dominant limb.

Table 2. Neuromuscular performance over successive judo matches in baseline, post-match 1, post-match 2, post-match 3 and post-match 4

Performance	**Pre**	**Post-match 1**	**Post-match 2**	**Post-match 3**	**Post-match 4**
SL_{CMJ}					
JH_D (cm)	27.1 ± 3.8	26.7 ± 4.3	26.6 ± 4.4	27.0 ± 4.4	28.0 ± 4.2
JH_{ND} (cm)	27.2 ± 4.2	26.8 ± 3.9	27.2 ± 5.6	28.0 ± 4.4	27.7 ± 3.9
MPO_D (W)	1155.5 ± 159.1	1189.2 ± 200.4	1179.5 ± 195.4	1176.4 ± 175.5	1203.8 ± 236.5
MPO_{ND} (W)	1193.3 ± 197.5	1225.8 ± 190.3	1185.6 ± 193.9	1236.6 ± 214.3	1225.7 ± 190.5
PPO_D (W)	2190.5 ± 312.2	2263.8 ± 388.9	2253.5 ± 382.6	2251.0 ± 348.1	2296.1 ± 460.4
PPO_{ND} (W)	2379.7 ± 474.1	2335.4 ± 366.9	2265.7 ± 382.0	2361.6 ± 413.4	2342.4 ± 369.8
PF_D (N)	1459.3 ± 223.7	1477.4 ± 254.5	1475.8 ± 283.9	1471.9 ± 266.6	1468.0 ± 256.5
PF_{ND} (N)	1523.9 ± 250.3	1487.5 ± 231.2	1487.8 ± 239.7	1505.0 ± 271.1	1495.2 ± 245.0
PV_D ($m \cdot s^{-1}$)	1.84 ± 0.18	1.86 ± 0.15	1.84 ± 0.19	1.85 ± 0.19	1.87 ± 0.19
PV_{ND} ($m \cdot s^{-1}$)	1.96 ± 0.34	1.89 ± 0.19	1.84 ± 0.18	1.89 ± 0.21	1.87 ± 0.18
VI_D (N·s)	181.7 ± 24.7	184.0 ± 33.8	180.3 ± 27.0	187.9 ± 26.5	181.9 ± 24.7
VI_{ND} (N·s)	195.2 ± 37.6	191.4 ± 30.1	174.0 ± 32.2	189.7 ± 31.3	178.1 ± 39.0
SL_{SLJ}					
D (cm)	173.4 ± 22.8	174.8 ± 27.8	177.0 ± 28.7	172.0 ± 29.1	181.3 ± 30.2
ND (cm)	172.3 ± 29.1	177.4 ± 34.3	178.4 ± 33.7	176.0 ± 36.2	171.5 ± 33.9
HGS					
D (kgf)	58.4 ± 11.6§#†$£	55.2 ± 9.8*§†$£	52.3 ± 10.1*#†	47.7 ± 9.0*#$	47.9 ± 9.9*#
ND (kgf)	56.3 ± 7.7§#†$£	50.9 ± 7.8*§†$£	47.2 ± 8.0*#†	44.3 ± 8.2*#$	46.0 ± 8.7*#

SL_{CMJ}: single leg countermovement jump, SL_{SLJ}: single leg standing long jump, HGS: handgrip strength, JH: jump height, MPO: mean power output, PPO: peak power output, PF: peak force, PV: peak velocity, VI: vertical impulse; D: dominant, ND: non-dominant, *Different from pre; #Different from post-match 1; $ Different from post-match 2; † Different from post-match 3; £ Different from post-match 4.

FIGURE LEGENDS

Figure 1. Neuromuscular asymmetry in single-leg jump metrics in the pre, post-match 1, post-match 2, post-match 3 and post-match 4. (A) = Jump height, (B) = Peak power, (C) = Mean power, (D) = Peak force, (E) = Peak velocity and (F) = Impulse. (G) = Standing Long Jump. (H) = Handgrip Strength *Significant difference from pre, post-match 1, 3 and 4.

Figure 2. Individual direction of asymmetry in all conditions (pre-match 1 and after each match) for (A) jump height in single leg countermovement jump test (SL_{CMJ}) and (B) handgrip strength.

*Note: above 0 means asymmetry favors the right hand; below 0 means asymmetry favors the left hand.

Figure 3. Bilateral index (BI) of handgrip strength measures throughout the successive judo matches. *Significant difference from post-match 4.

Figure 1.

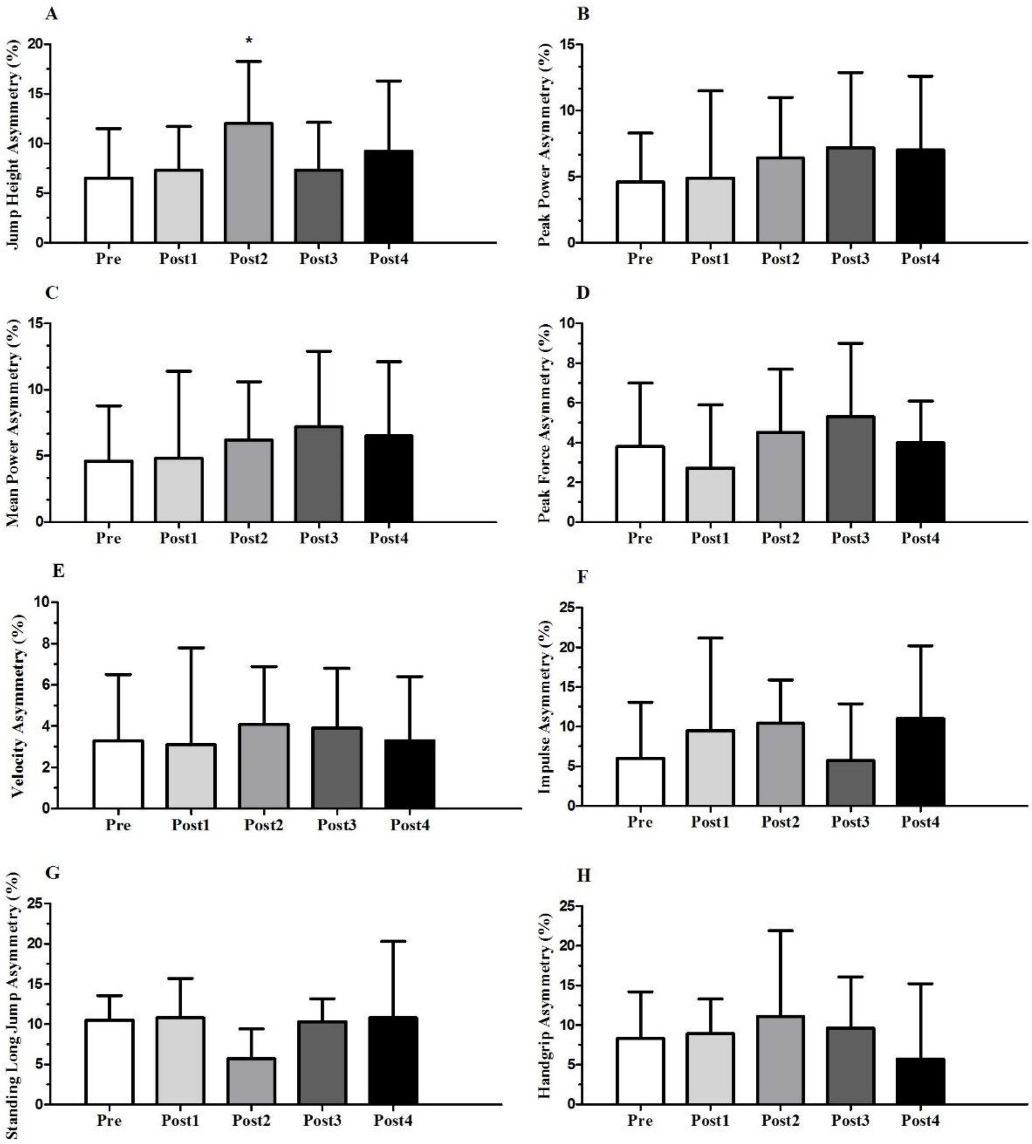

A
Jump Height Asymmetry (%)
B
Peak Power Asymmetry (%)
C
Mean Power Asymmetry (%)
D
Peak Force Asymmetry (%)
E
Velocity Asymmetry (%)
F
Impulse Asymmetry (%)
G
Standing Long Jump Asymmetry (%)
H
Handgrip Asymmetry (%)
Pre
Post1
Post2
Post3
Post4
*

Figure 2.

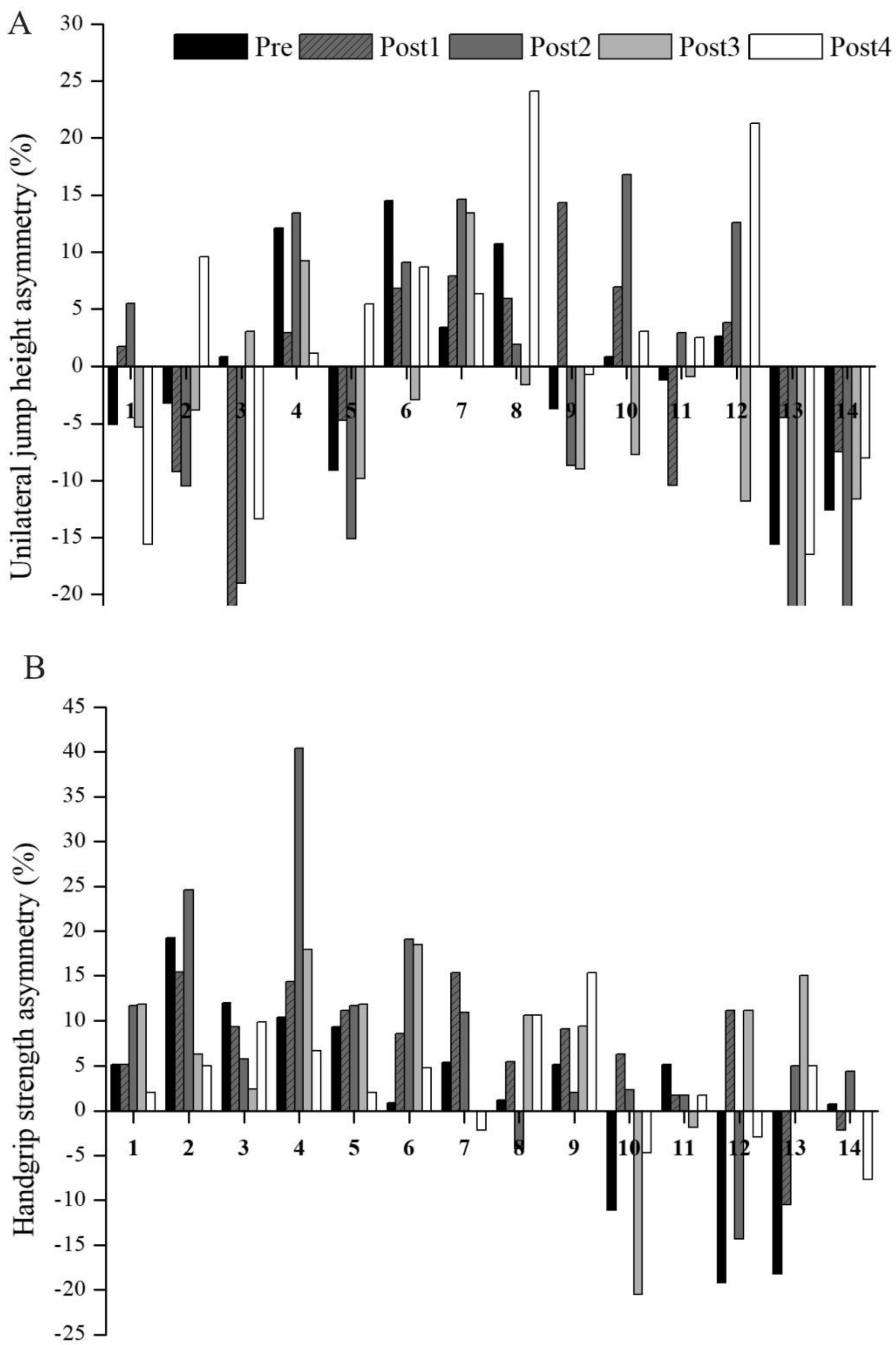
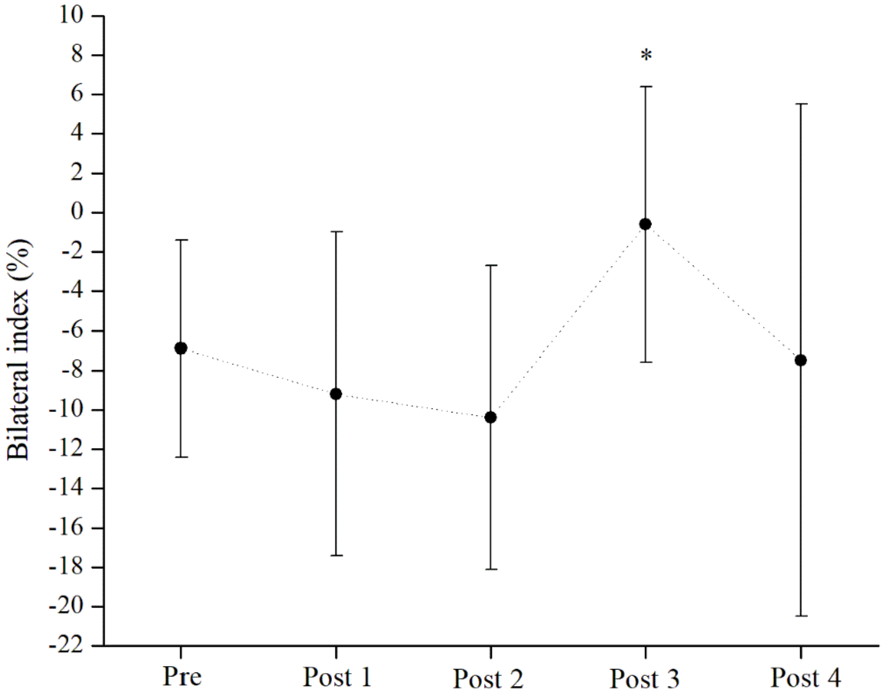

A
B
Pre
Post1
Post2
Post3
Post4
Unilateral jump height asymmetry (%)
Handgrip strength asymmetry (%)
30
25
20
15
10
5
0
-5
-10
-15
-20
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 3.



Bilateral index (%)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
*
Pre
Post 1
Post 2
Post 3
Post 4